Optimal Energy and Demand-side Management with Location-based Services and Adaptive Data Mining Algorithms using an innovative web-based Energy Information System (EMIR)

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Abstract: Internet use, domestic energy consumption for electricity, demand-side management, consumers' education and their interaction for end-user Energy efficiency are focused in this paper. An increasing number of consumers from all levels of the society, cultures, lifestyles and social status have continuous internet access through ADSL connections. Those consumers will be targeted in order to collect and analyse their acceptability in new energy technologies and adaptive energy services. Energy Information Systems (EIS), which monitor and organize building energy consumption and related trend data over the Internet, have been evolving over the past decade and can be considered as a part of a specialized DSS. The above concept performs key energy management functions such as organizing energy use data, identifying energy consumption anomalies, managing energy costs, and automating demand response strategies and focused customer profiling. The aim of this paper is to develop an innovative internet-based methodology that brings together energy consultants, consumers and modern IT technologies under the umbrella of the Energy Governance. Consumers' interaction with energy consultants and IT Services will be a valuable step into implementing efficiently EU policies (2002/91/EC & 2006/32/EC), focusing on the introduction of informative billing and intelligent energy analysis through the end-use energy efficiency directive and the use of Energy Services (ESCOs). Furthermore, the involvement of utility companies will be valuable in order to manage efficiently electricity production and to plan demand side management and energy efficiency programs. Energy-related market will be enforced and benefited through targeted information, behavioural changes and innovative accessibility internet tools. The first National Greek Case study is presented with real energy measured results and important intelligent Graphs. The system and methods are protected by two successful national patent applications to OBI

1. Short Overview

The increasing number and speeds of internet connections can be seen as the tool for measuring electricity and consumers' behaviour on energy consumption, giving an added value to consumer access and interactive approach to energy and energy related solutions. An increasing number of consumers from all levels of the society, cultures, lifestyles and social status have continuous internet access through ADSL connections. Those consumers will be targeted in order to collect and analyse their acceptability in new energy technologies. The aim of this paper is to develop an internet-based methodology that brings together energy consultants, domestic consumers and ESCO philosophy. Consumers' interaction with energy consultants will be a valuable step into implementing efficiently EU policies, focusing on the introduction of informative billing through end-use energy efficiency directive and the use of renewable energy sources. Furthermore, the involvement of utility companies [6] will be valuable in order to manage efficiently electricity production and to plan demand side management and energy efficiency programs. Energy-related market will be enforced and benefited through targeted information, behavioral changes and innovative accessibility internet tools.

A modern Decision Support System (DSS) can be defined as computer-based tool, or a more complex Information System structure, used to support and generate decision-making and problem solving. Although this definition applies very well to decision-making [8] in many purely technical areas, it falls short of reflecting one extremely important aspect of the decision-making process in water resource systems: the role of human factor. Energy Information Systems (EIS [3]), which monitor and organize customer energy consumption and related trend data over the Internet, have been evolving over the past decade and can be considered as a part of a specialized DSS. The above concept performs key energy management functions such as organizing energy use data, identifying energy consumption anomalies, managing energy costs, and automating demand response strategies and focused customer profiling. In this paper, a modern and innovative web-based intelligent Energy Information System [1], [2], [12] is briefly described, for an optimal energy sources management and minimisation-control of home and factory-based energy consumption (**EMIR system - Energy Management & Intelligent Reporting**).

2. Energy Information Systems

The primary use of an EIS (Energy Information System) is to assist facility operators, owners, and other decision-makers in managing building energy use. Real-time or daily updating of hourly energy consumption data allows users to evaluate building energy performances that are otherwise difficult to observe. Since most EIS products provide real-time or daily updates of hourly trend data, facility operators can verify the impact of a change in an operational strategy immediately following or within a day of the action. In the absence of an EIS, an impact evaluation would have to be postponed until the monthly utility bill has arrived. Besides, utility bills will only reflect significant operational changes. It is also difficult to attribute a reduction (or increase) in utility bill to a specific action taken on a building.

The method is used for effective Energy Knowledge management in the newly opened Greek Energy Market. The system is designed and developed to analyze, optimize and manipulate energy data and energy practices, through a web portal. The energy data are accessed from ADSL-based databases and hypercubic grid structures or from internet-based heterogeneous sources, by using web Internet services. The system adopts a powerful combination of current software frameworks based on the J2EE specification [5]. Dynamic Java Server Pages and XML-XSL technologies provide effective energy data interoperability. The core intelligence of the on-line web system was developed using Matlab programming and the powerful MATLAB Web Server, connected in a clustered n-tier network. The system, which is currently on-line, was tested with real energy data and statistical graphical outputs were produced for result analysis and web-based reasoning demonstration.

As back-end knowledge management procedure, a powerful clustered hypercubic isomorphic topology [2] is used for the first time, with the additional use of traditional database technology.

This web-based functionality can be enriched with many add-on services in order to create a complete Information System that will act as the basic "ad-hoc broker" between free customers and energy providers, in the future opened Energy market

3. Basic Energy System Modeling

Modelling energy consumption [9], [10], [11] is a critical step on the path to constructing performance metrics that accurately reflect the impact of actions taken to manage energy. Modelling building or process energy usage normally involves determining the relationship between energy consumption data and some variable (such as temperature or production activity) that represents the *primary driver* of that energy consumption. For buildings, there is normally a direct relationship between the energy consumed by a building and the outdoor temperature. For production processes where energy use is largely determined by the physics of the process (such as heat-based and chemical processes), there is normally a direct relationship between the energy consumed and production volume. The process of building basic models involves the following steps:

1. Select a *baseline set* of energy and primary driver data from the historical data collected;
2. Create and test a *baseline model* of energy vs. the primary driver; and
3. Create one or more *target models* to track the performance of an energy management plan.

It is important to note that the modelling process described here is quite basic and will not generate robust energy consumption models in all circumstances. More sophisticated techniques for modeling industrial and commercial energy consumption are available, one example being the change-point models described in ASHRAE RP-1050, *Inverse Modeling Toolkit: Numerical Algorithms.*

In a typical EIS architecture the decision support system will enable experts and businesses to further manage data such as energy consumption profiles, optimal maintenance routines and costing issues

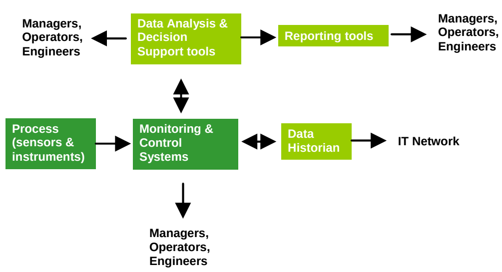

Fig. 1 - EIS Decision Support System

The identification of the best available practices from domestic users, industries and services sectors will reduce the dependence from high energy costs and will improve quality of living, products and services in the market

The data set selected over a defined length of time to represent the energy consuming behavior of some load (which may be a building or manufacturing process) before an energy management plan is implemented forms the *baseline data set.* This data set normally consists of two main variables: the energy consumption of a load and the primary driver associated with that energy consumption (which can include parameters such as temperature or production volume). The data collected for both of these variables will be represented in a common interval; for example, if energy consumption is totalled on a daily basis, for example, then production volume or temperature data needs to be aggregated into a daily value as well.
To obtain the most accurate model possible, the length of this baseline period should encompass the time period required for the load being studied to cycle through its entire operating range. In the case of a building, the baseline period will normally be at least one year in length to capture the energy consuming behaviour of the building across all seasons. In the case of a production line, the baseline needs to be long enough to capture normal variations in production volume.

4. Energy Governance and ESCO's

Energy service companies have already been established into the world market. In general, western European countries are using the ESCO's business tool for achieving energy savings and make their businesses profitable. Energy service companies market potential is greater than ever, since the energy cost is continuously increasing. The increased demand for managing the higher number of customers requires a very powerful tool that can meter, bill, consult and support energy efficiency projects.

Energy governance [17] is the holistic approach to manage end-use energy consumption. It provides low operational expenses because of the already developed infrastructure of information technology. Energy information systems (EIS) potential expansion, contributes to more accurate and quantifiable energy data. The contribution of energy governance to ESCO's industry will then increase the profitability of energy efficiency projects by reducing their operational costs. The creation of quality knowledge banks can also highly contribute to the decision making stages of every energy efficiency project before, due and after its completion providing to the customers' quality informative services.

5. Energy Services according to 2006/32/EC

Energy end-use efficiency and energy services directive purpose is to increase energy efficiency at every point of energy consumption.

The improved energy end-use efficiency will make it possible to exploit potential cost-effective energy savings in an economically efficient way. Energy efficiency improvement measures could realise these energy savings and thus help the Community reduce its dependence on energy imports. Furthermore, a move towards more energy-efficient technologies can boost the Community's innovativeness and competitiveness. The aim of the 2006/32 Directive is not only to continue to promote the supply side of energy services, but also to create stronger incentives for the demand side. In defining energy efficiency improvement measures, account should be taken of efficiency gains obtained through the widespread use of cost-effective technological innovations, for instance electronic metering. Furthermore, the funding of supply and the cost of the demand side has an important role to play in energy services. The creation of funds to subsidise the implementation of energy efficiency programmes and other energy efficiency improvement measures and to promote the development of a market for energy services can constitute an appropriate tool for the provision of non-discriminatory start-up funding in such a market.

The fully implementation of 2006/32 Directive will provide the appropriate tools at national and European level for environmental protection, reduction in energy consumption and protection of the citizens income.

6. Matlab Server & EIS Development

The basic middleware of EMIR system is totally based on the Matlab technology. Matlab has documentation based on external interfaces describing how to call m-files from C/C++ /Fortran/Java & C#. Developer can easily access matlab through Component Object Model (COM) and Dynamic Data Exchange (DDE) support at Microsoft Windows based platforms. Also, there are built-in C Routines to call matlab from other languages. These routines are accessible for both Microsoft Windows and all POSIX based (Linux, UNIX like) operating systems. C and C++ languages are not well formed and not a rapid choice for developing N-Tier applications (for example, Remote Method Invocations and Web Services) like C#. As long as it seems C# on .NET Framework is a suitable solution, C# can only implement C or C++ routines in unsafe blocks, which cause stack overflow. It can be accepted as a satisfactory solution, Java Native Interface (JNI) technology can wrap C routines in Java. On the other hand, Matlab has a product called "MATLAB Compiler" to generate runtime [5] based DLLs, C# Assemblies or Java classes to use m-code in C, C++, C# or Java. Main purpose is to reduce time in development and easy code management. Besides, m-Compiler has limitations and restrictions. The developer may face with challenges in this solution. There are some approaches that use C Routines of Matlab to overcome this issue. One of them is a toolbox called MATLAB Web Server [5]. MATLAB Web Server use Common Gateway Interface (CGI) to transfer data from web to MATLAB. Matlab Server Pages (MSP) is an open source technical web programming language using matlab engine in background. MSP supports "3-Tier Architecture"; Web Tier, Business Tier and Database Tier. Also, MSP consists of "distributed computing" and "parallel processing" via remote procedure calls and web services. MSP uses JavaServer Pages technology to define Custom Tag Libraries, called Matlab Tag Library Definitions & MATLAB Remote Method Invocation.

In generalal, MSP architecture can be summarized as follows:

- MATLAB Server Pages connects to matlab engine with Stefan Mueller's Java Wrapper Class called JMatLink [5]. MSP Java classes drive JMatLink for JavaServer Pages by adding new methods for matlab features, JSP page output, imaging on browser, remoting and web services
- By default, MSP comes with MySQL JDBC driver. JSP Standard Tag Library has SQL tag library, which can run SQL expressions on database server. Expression Language Mechanism handles MSP Tag Library and SQL Library interactions. From MSP, developers can connect to a database server. They can retrieve data from MATLAB and store to database and vise versa. This is the Database Tier - EIS Tier.

- JavaServer Faces is a technology that has advanced user interface components for JSP and can define navigation rules for business processes by running beans in background. MSP uses Apache Software Foundation MyFaces implementation. The pages that use JSF have MLSPX extension in MSP.

Default extension is MLSP for MSP. MLSPXs can call beans and do operations defined in them. Developers can add their beans to MSP. Matlab Beans (m-beans) work like a Plug-in Logic. If developers use remote-methods in Matlab Beans, they can separate business logic and business rules to another server. This puts "Business Tier" to forward. MSP has several demos and examples on how to use MSP Engine. Client systems can be dynamic web pages, a part of distributed computing and web service operations. These usage examples can be called as a "Client Tier".

Main Classes have several methods to handle custom JSP Tags at Web Server. For example:

<Matlab:Engine> tag on Web Server runs:

```
public void engineOpen() {
                    // Reads MSP settings from Bundle.
                    ResourceBundle rb =
          ResourceBundle.getBundle("MSP");
                    // Code Dir is the base for
MATLAB              M-Files, Simulink Models and
                    // Matlab Server Files. All
                    runnable codes and models must be
                    // there.
                    Code_Dir =

          rb.getString("Code_directory");
                    // Image Dir is the base for
                    MATLAB created images.
                    Image_Dir =

          rb.getString("Image_directory");
          // System out out for Java debugger.

          System.out.println("MATLABServer
                    Pages Engine");
                    javaLink = new JMatLink();
                    javaLink.engOpenSingleUse();
                    // Running MSP at Code Dir.
                    javaLink.engEvalString("cd '" +
                    Code_Dir + "'");
                    }
```

This class handles all RMI operations, database connectivity, distributed computing, and web services. Web Server Layer acts as a RMI Client to connect to Application Server. This Web Server has a Remote Method Invocation Interface to MSP Main Classes located at Application Server. This interface includes all methods in these classes. So application in this server can use all functionality of MSP as running on local. Programmers can deploy applications on this server with an easy syntax:

test.mlsp

```
-------------
<html>

<head>
<%@ include file="/Scripts/header.inc" %>
<title> Hello World! </title>
</head>
<body>
<Matlab:Engine>
            <Matlab:Command cmd="rand(1,10)"/>
            <Matlab:WriteData name="ans"/>
</Matlab:Engine>
</body>
</html>
```

The Web Server connects to Database Server Layer to exchange data using JSTL SQL Library and MSP Tag Libraries.

7. Technical Architecture of EMIR System

In order to show and describe the functionality of the Matlab Server Pages (MSP), a web-based Energy Decision Support System was used in order to integrate Matlab functions and tags to the energy analysis procedure (Fig. 2). A modern Decision Support System (DSS) can be defined as computer-based tool, or a more complex Information System structure, used to support and generate decision-making and problem solving.
In a typical EIS architecture [12], [14], the EIS server hardware and software located at the EIS service provider's physical site record interval data via the Internet. The EIS receives these data from signals dispatched by meters installed in a customer's building, or directly communicates with meters. The EIS users can access the server with a password, and access the archived energy data either in real-time or in hourly, or daily updates from anywhere via a web browser. This web-based functionality can be enriched with many add-on services in order to create a complete Information System that will act as the basic "ad-hoc broker" between free customers and energy providers, in the future opened Energy market. Two different environments were involved in the development of the web-based evaluation tool interface: hyper-text markup language (HTML) standards with the addition of some java server pages (JSP) under J2EE specifications, and advanced Matlab code [5], which permits the dynamic mathematical development of the evaluation model described above. The Matlab web server toolbox [5], [7] was effectively used by combining java language, to produce dynamic Matlab server pages.The communication was pre-served, through internal java objects, which are incorporated in the apache tomcat server. Remote Matlab method invocation was achieved by this way and by combining CGI-

based POST methods to the Matlab web server; a very powerful Matlab application server was produced. The developed system allowed the creation of compact programs, called Matlab beans and the execution of those interconnected beans.
The application, using web GUI facilities sends data, through java calls and post methods to the Matlab beans and vice versa. The system support parallel processing algorithms and form the first simulations that took place in Medialab (NTUA), matlab parallel toolbox was used, in order to parallelize norm distance calculation. By using Valiant algorithm, internal package blocks where minimized statistically.

The overall performance output was more than positive, allowing the algorithm to be executed concurrently to any energy customer, using special screen-saver programs.

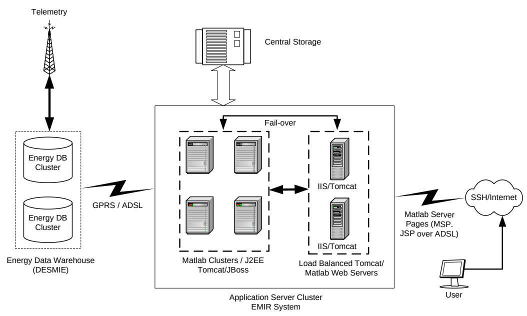

Fig. 2 - EMIR System Technical Architecture

8. ADSL-based AMR Methodology

The Web Enabled Electric Meter (WEM-MX) [15] that is used for the Greek pilot, is an Internet enabled, broadband ready smart electric meter for commercial and industrial applications (Fig. 3). It can be deployed as a primary meter, sub meter or used for other electric metering applications such as demand reduction. Besides tracking peak demand (kW) and energy consumption (kWh), this advanced meter integrates many important features and provides enhanced functionality.

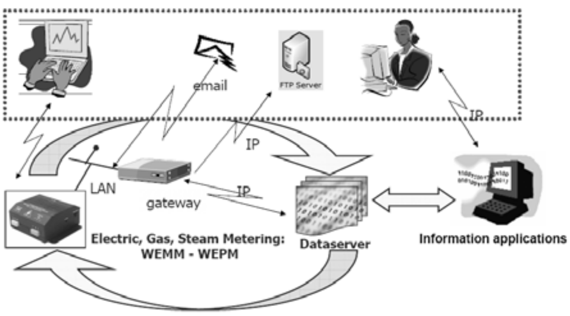

Fig. 3 - AMR topology used in Greek Pilot

Its open system design facilitates world-wide deployment to populate applications with real time data based on accurate measurements. This electric meter is designed to meet requirements for data on demand from multiple users. Traditional meters focus only on single user applications at fixed time intervals. It provides peak demand (kW) with a date and time stamp informing you as to when the peak demand occurred. It also has the capability to periodically record and store interval data usage (load profile) based on a user defined interval of 1 minutes to 60 minutes or more. This functionality helps identify where, when and how much energy was consumed say, every 15 minutes. It can also store energy consumption by time-of-use (TOU). This allows end users to identify how much energy was consumed during different periods of the day. Configuration settings are done via its on board web server

- <XML>
- <METER_ID>11111111111111110125</METER_ID>
- <METER_ADDR>WEM Location</METER_ADDR>
- <METER_TIME>08/15/07 12:02 Wednesday</METER_TIME>
- <DMD_INT>15</DMD_INT>
- <NUM_SUB_INT>0</NUM_SUB_INT>
- <SRL_NUM>1111111111110125</SRL_NUM>
- <CURR_TIER>A</CURR_TIER>
- <NUM_DMD_RESETS>5</NUM_DMD_RESETS>
- <MAX_KW_DEL>89.604</MAX_KW_DEL>
- <MAX_KW_DEL_T>08/14/07 12:43 </MAX_KW_DEL_T>
- <CUM_KW_DEL>375.554</CUM_KW_DEL>
- <CONT_CUM_KW_DEL>465.158</CONT_CUM_KW_DEL>
- <MAX_KVAR_DEL>8.035</MAX_KVAR_DEL>
- <MAX_KVAR_DEL_T>08/14/07 14:58 </MAX_KVAR_DEL_T>
- <CUM_KVAR_DEL>114.964</CUM_KVAR_DEL>
- <CONT_CUM_KVAR_DEL>122.999</CONT_CUM_KVAR_DEL>
- <KWH_DEL>3525.673</KWH_DEL>
- <KVARH_DEL>668.024</KVARH_DEL>
- </XML>

Fig. 4 - XML-based Energy Data from AMR

The output of the measured energy data are in XML format (Fig. 4) and thus can be easily imported to the EMIR middleware for direct processing from the web algorithms. XML data are generated every 15 mins (traditional Demand side interval) and are uploaded automatically to a dedicated FTP server that acts as a gateway to the created Energy Warehouse that was used. Sequentially, the generated XML data are inserted automatically through data cleansing and ETL mechanisms to a dedicated database and are processed by Matlab beans, in order to create data mining outputs and table results.

9. Greek Case Study in Schools & Buildings

The first Greek Pilot web load profiling project was executed in one Greek Private School and two buildings in the region of Athens. The above AMR methodology was used, with WEM-MX meter (Fig. 5) and web XML energy data integration. EMIR system with hypercubic clustering theory [2], [14], [18] was used to analyse and mine energy data in order to extract trends. Values and physical parameters that were generated and used were kWh, C02, kWh/m2, Current and Voltage, Heating and Cooling variables. Also national variables from DESMHE HTSO [19] were used (SMP, MWh national peak consumption) in order to provide Graphs correlating SMP and Peak consumption for optimal Demand-side management methodologies. Additionally, location-based services were also integrated to the existing Matlab middleware (Fig. 8) for geo-spatial correlation [16] of profiling and local climate conditions (temperature, m2, opaque, etc).

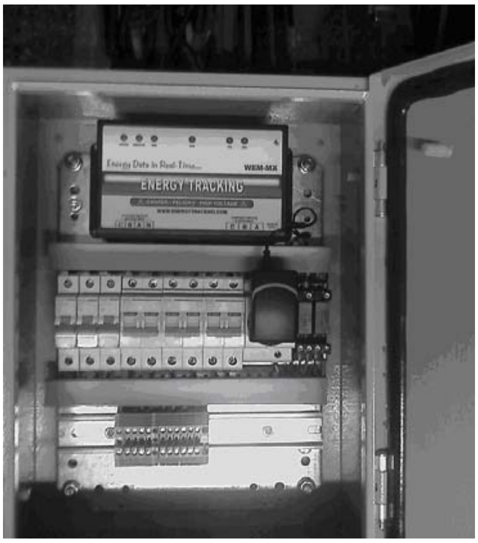

Fig. 5 - AMR installation to Greek School

From the data and the output graphs, many results and comments can be made, especially for the effectiveness and the power of EMIR EIS and its embedded algorithms (EnergyRank [2], [13], [14]). Firstly, it can be said that there are huge possibilities of energy conservation and minimization using personalized Energy Services from ESCOs, given the fact that the characteristic curves (kWh/m2) and energy load profiles are highly correlated.

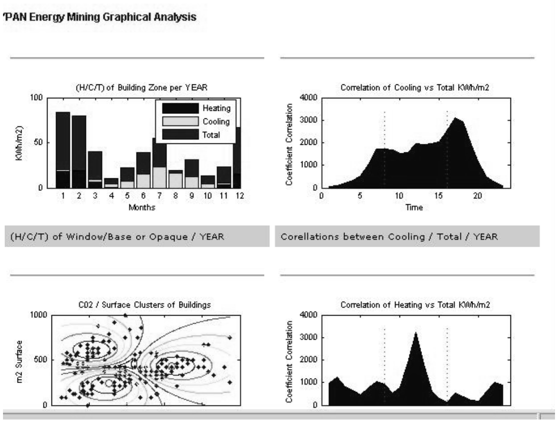

Fig. 6 - EMIR System Technical Architecture

From Fig.6 it can be seen that the energy mining algorithms for the private school give correlated profiles (autocorrelation functions for Heating and Cooling) and this can direct energy services according to specific time slots (elastic periodicity) with variable price philosophy. Specific clustering methodologies, group together C02 emissions from various other buildings (in the same or different regions) and EMIR system provides correlated clustering outputs with their surface (m2) and load profile per month, indicating where there is an old building that needs services from an ESCO, or a new building that needs probably different methodologies (CHP, Gas integration, RES, etc). Adaptive peak analysis and seasonality trend modelling (Fig. 7)

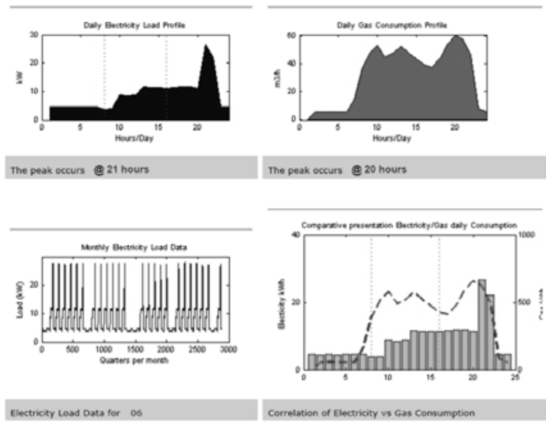

Fig. 7 - EMIR System Technical Architecture

of the School and some buildings, from EMIR methods (six months energy data), indicated also strong correlations and strict periodicities. Peak analysis, correlated with kW peak and Gas consumption gave great hidden trends for CHP services or Demand Response programs to reduce peak load and shift loads towards other time slots with lower price of kW. Variable kW prices correlated with Gas prices and gain margins from the minimised load, give great results for an ESCO, in order to invest on personalized energy services. The system, using back-end energy crawlers, ranks the buildings (energy customers) and generates high probable customers.

Furthermore, the combination of location-based services and embedding Google Maps to the existing middleware, give great geo-spatial results. Using Google markers (Fig.8) geo-correlated load profiles are indicated on a dynamic map that changes according to the variable consumption. Geographical ranking of max customers with periodicity or correlated peaks are indicated with EMIR system, giving the opportunity to an ESCO or an Energy Consultant/Company to direct its services towards specific customers with positive ROI margin and high probability of energy minimization. Energy markers are dynamic and an overall geo-spatial search can be effectuated, over regions that are measured with our system. Micro-climate conditions and local physical parameters (temperature, humidity) were also included into the middleware, in order to produce correlated data for contraction companies (building according to best energy characteristics)

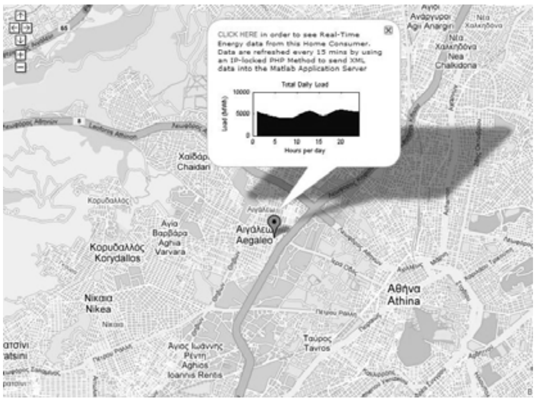

Fig. 8 - EMIR Location based Services in Energy (Building in Aigaleo region in Athens)

Correlated graphs were also generated from measurements inside a building or inside the School (pool, various Electro-Mechanical devices, etc). Correlating those measurements over time (Fig. 9) can expose hidden energy patterns and trends for Demand Response. For example in Fig. 9, there is a sequential periodic trend of 3 E/M devices inside the building. This hidden trend indicated a sequential peak of energy that was corrected by shifting two devices to neighbouring time slots.

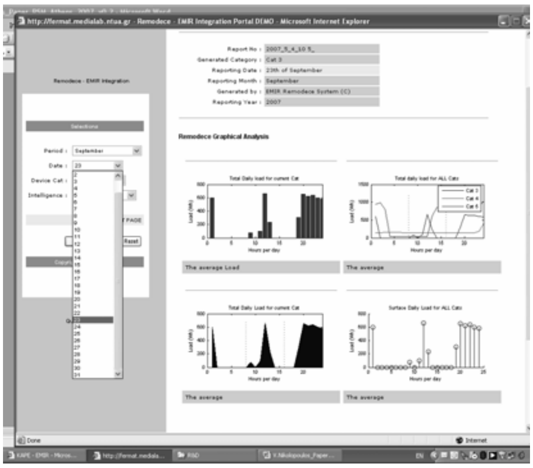

Fig. 9 - Statistical energy trends from BMS entries

Finally, from National consumption data (DESMHE - HTSO) national load profiles were used for adaptive SMP (System Marginal Price) analysis. EMIR system, using hypercubic clustering, provides best time slots where with high SMP price, the National consumption is at low level, giving high ROI margins probabilities to Energy providers. Time series Analysis was also used (Fig. 10).

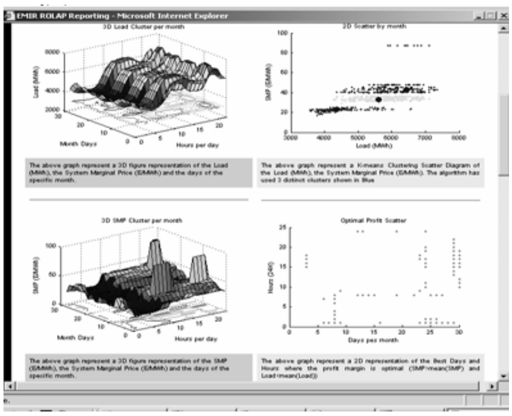

Fig. 10 - SMP clustering analysis for DESMHE

The above Energy Mining analysis, was effectuated from EMIR system and the patented algorithms that reside inside the Matlab middleware (MSP). Various application Graphs were used in order to indicate the ability of the system to analyse, manage and provide hidden energy information to an ESCO for Energy Services provision. The results indicated also that we could have extremely important results and create actions, if we use the stored data to extract information and create useful energy knowledge.

10. Further Work

Energy management practice has traditionally put greater emphasis on the technology involved in energy efficiency efforts than it has on the management of those efforts. There is no question that new technology plays an important role in helping organizations increase their energy efficiency, but it is also true that projects can see increased (and more consistent) savings by adopting the performance management approach integral to modern quality and energy management programs. Information systems are becoming a key part of modern energy management practice, especially as the hardware and software components that make up these systems become more widely available. In the past such energy information systems were often prohibitively expensive, but advances in recent years have been steadily decreasing the cost involved to monitor an increasing number of measurements. As the costs involved in automating data collection continue to drop, the “total cost of ownership” for these systems will increase on the data management and information processing side of the equation.

The value of future energy information systems will not be in the quantity of data they can collect, but rather in the quality of insight they can deliver.
The discussion and examples in this paper focused primarily on targeting reductions in energy consumption, but the performance metric approach can also be applied to several other aspects of managing energy systems and equipment. Examples illustrating how this approach might be extended include the following:

• *Energy cost.* Utility rates can be applied to the performance metric process described above to track and manage energy costs. Models can be used to compensate for changes in primary drivers (such as temperature and production volume) to more accurately calculate the savings realized by energy efficiency projects.
• *Energy reliability [9].* Measurements related to the "health" of equipment can be added to an energy information system and used to generate performance metrics focused on energy system reliability.
• *Forecasting [9].* Once energy consumption has been modelled, future consumption can be estimated based on projected values for the primary driver of consumption (such as temperature or production volume). Risk assessments for energy consumption can be generated by applying a range of expected primary driver values.
Energy management practice has seldom held much mind share with executives even though energy is often critical to the operation of their organization. Greater mind share can be won when energy management activities are cast more in business terms than in technical terms, and their contribution to the bottom line highlighted.

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